Inherent Variability in the Efficacy of the USDA Raw-Pack Process for Home-Canned Tomatoes

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ABSTRACT

Studies of the USDA raw-pack process for home-canned tomatoes, using *Bacillus licheniformis* spores as the target organisms, revealed that water bath size and canning load did not affect heat penetration rates in pint jars of tomatoes. However, because decreases in the water bath size and canning load shortened the come-up time and, as a result, lowered the maximum cold-spot temperature; the calculated process lethalities were lessened. Properly executed canning runs which varied in water bath size, amount of water in the bath, and load size produced calculated lethalities ranging between 1 and 7 log reduction.

INTRODUCTION

THE HOME CANNING of tomatoes is popular as both a summer pastime and as the subject of innumerable research reports. As early as 1945, Tischer and Esselen reported a high rate of spoilage in home-canned foods. More recent studies indicate that the picture has not improved. Mundt et al. (1978) found that 33% of the home-canned tomato samples examined contained viable microorganisms. Another survey found *Bacillus sp* in 40% of the tomato jars analyzed (Fields et al., 1977). Considering the relatively low heat resistance of some bacillus spores (Montville and Sapers, 1981), it must be concluded that home canning recommendations for tomatoes either are not being followed, or need further improvement.

Considerable attention has been focused on determining the pH of tomatoes (Paulson and Stevens, 1974; Sapers et al., 1977; Powers and Goodwin, 1978), factors affecting the pH of tomatoes (Sapers et al., 1978a; 1978b), and the need for acidification (Powers, 1976; Sapers et al., 1978c). Some of the microbial aspects of the problem which have been examined include the thermal resistance of *B. thermoacidurans coagulans* (Anderson et al., 1949), factors affecting the growth of *B. coagulans* in tomato juice (Rice and Pederson, 1954; Jones and Ferguson, 1961), and the ability of *Clostridium sporogenes* spores to survive the processing of home-canned tomatoes and tomato juice (Savani et al., 1978; Williams and Maki, 1980).

Although it is generally accepted that *Clostridium botulinum* spores will not germinate, grow, or cause toxigenesis in foods at pH $\leqq$ 4.6 (Ito and Chen, 1978), low pH is only sporostatic. *C. botulinum* spores remain viable in tomatoes at pH 4.2 for more than 180 days (Odlaug and Pflug, 1977). Consequently, investigations of conditions under which the pH of tomatoes can become elevated are of special interest. The ability of *Cladosporium* and *Penicillium sps* to elevate the pH of tomato juice and allow toxin production by *C. botulinum* was first reported by Huhtanen et al. (1976). Odlaug and Pflug (1979) reported similar results using *Aspergillus gracilis.* A wide variety of pH-elevating fungi can be isolated from home-canned tomatoes (Mundt et al., 1978). It has been previously demonstrated that *B. licheniformis* can elevate the pH of an acidic model system and permit *C. botulinum* toxigenesis (Montville, 1982). That study also noted that the lethality of the USDA raw-pack tomato process for *B. licheniformis* spores was affected by canner size. We were concerned that this variation might allow *Bacillus sp* to survive the canning process, grow in a poorly sealed jar, elevate the pH, and allow subsequent toxin production by *C. botulinum.* Even if this scenario did not occur, the variability in process lethality for *B. licheniformis* would be important from a spoilage standpoint. If *B. licheniformis* spores survived, then spoilage by organisms such as *B. coagulans,* whose spores are more heat resistant, could be expected. The objective of this study was to investigate factors affecting the calculated lethality of a properly executed USDA raw-pack process for home-canned tomatoes.

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MATERIALS & METHODS

PINT JARS of peeled quartered Roma VF tomatoes were processed in their own juice according to the USDA raw-pack procedure (USDA, 1975) which specifies that the sealed jars be placed in a boiling water bath and, when boiling resumes, be processed for 35 min. Trials with a 45 min process time were done in a similar fashion. The process variables were canner size, the amount of water in a given canner, and the number of jars per load in a given canner. These quantities are specified in the first four columns of Table 1.

The methodology for determining heat penetration and calculating process lethalities, as well as experimental evidence from inoculated packs which validate the assumptions used in these calculations, have been published previously (Montville, 1982). Briefly, a rigid thermocouple was imbedded in a tomato at the geometric center (cold spot) of the product jar. This was used to measure the cold-spot temperature during the come-up time, the 35-min boiling water bath process period, and the cool-down period. These data were used with decimal reduction times and the z value (D_{95} = 4.5 min, z = 14.9°C) for *B. licheniformis* spores in tomato puree at pH 4.4 (Montville and Sapers, 1981) to calculate the lethality for each process using the method of cumulative lethal rates (Nickerson and Sinskey, 1972).

RESULTS & DISCUSSION

THE CALCULATED LETHALITY of the USDA raw-pack process for tomatoes ranged from 1.0-7.4 log reductions of *B. licheniformis* spores depending on the canning conditions (Table 1). This variability could be attributed to several factors. The large canner gave calculated lethalities of 3.1–7.4 log reductions while the use of a small canner produced calculated lethalities of 2.5–3.2 log reductions. In a canner of a given size, the number of jars in the load also affected the process lethality as can be seen by comparing run 6 with runs 2 or 3, or run 10 with runs 7 or 8 (Table 1). In the worst case situation, the use of a saucepan resulted in a process with a lethality of only 1.0 log reduction.

The equation for heat penetration in the experimental system (illustrated in Fig. 1) can be expressed as

$$dT_{cs}/dt = m_{to}c_{to}(T_{wb} - T_{cs})$$

where T = temperature, t = time, m = mass, c = specific

Table 1—Effect of canner variables on come-up time, total process time, cold spot temperature and calculated lethality

Run #	Canner size	# of jars	Liters of water[a]	Come-up[b] time (min)	Total process[c] time (min)	Max T°C cold spot	Calculated lethality (log reduction) *B. licheniformis* spores
1	Large	8	18	18	143	93	4.5
2	Large	8	18	25	120	97	7.4
3	Large	8	18	25	150	95	7.1
4	Large	8	22[d]	20	130	93	5.1
5	Large	8	22[d]	22	135	91[e]	3.9
6	Large	4	20	8	111	91	3.1
7	Small	6	12	9	134	91	3.2
8	Small	6	12	10	115	90	2.7
9	Small	4	13	8	113	91	3.1
10	Small	3	14	6	106	89	2.5
11	Saucepan	1	3	0	100	83	1.0

[a] Amount required to cover top of jar with 1-1/2 in. of water.
[b] Time required for water to resume boiling after cans put in canner.
[c] Come-up time + 35 min + time during cooling to reach 60°C.
[d] Amount required to cover top of jar with 2-1/2 in. of water.
[e] Initial cold spot temperature = 19°C; all other runs = 23°-25°C.

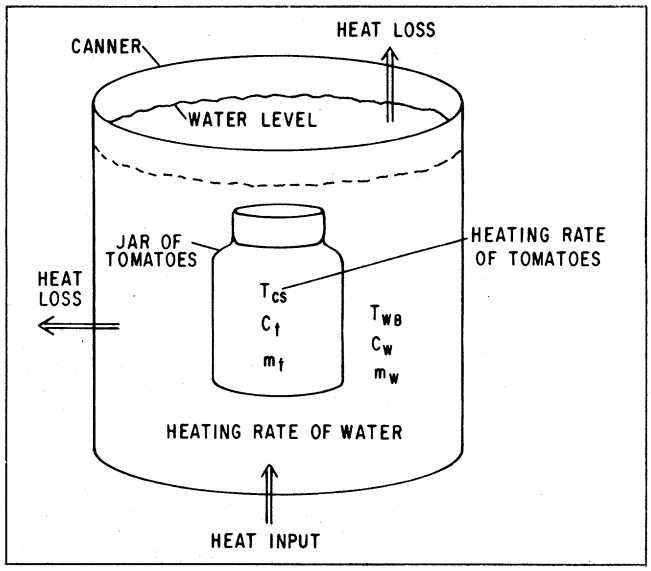

Fig. 1—Schematic depicting variables which affect heat transfer during the boiling water bath processing of a jar of tomatoes. T = temperature, c = specific heat, m = mass, t = tomatoes, cs = cold spot, wb = water bath, and w = water.

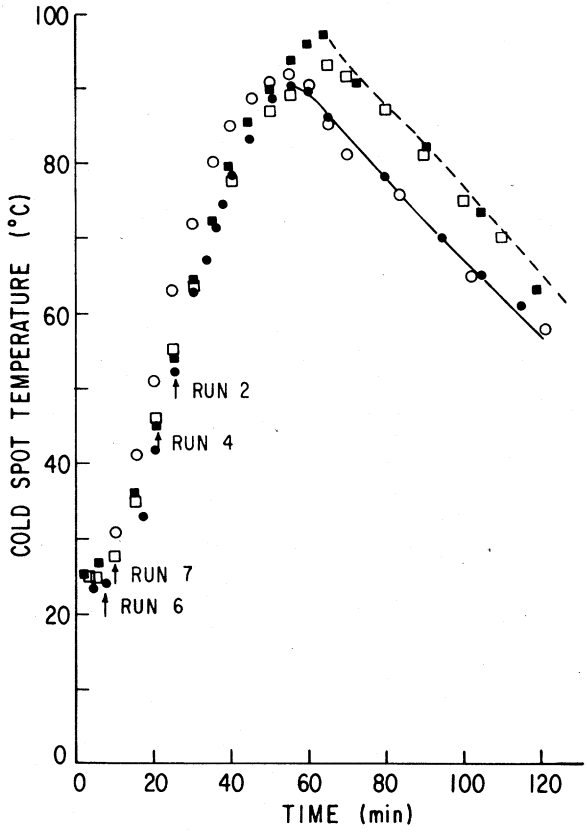

Fig. 2—Representative heat penetration curves for pint jars of tomatoes. Arrow indicates resumption of boiling during run indicated on graph: • Small canner, full load (run 7); ○ Large canner, half load (run 6); ■ Large canner, full load (run 2); □ Large canner, full load, excess water (run 4).

heat, and the subscripts cs = cold spot, wb = waterbath, and to = tomatoes. The heating rate (dT_{cs}/dt) of the cold spot was not affected by canning parameters. Regardless of the process variables, the initial T_{wb} ranged from 94-97°C, while the initial T_{cs} was 23-25°C. Thus a variation of, at most, 5°C in the ΔT term (i.e., $T_{wb} - T_{cs}$) would not be significant compared to the total ΔT of about 70°C. Fig. 2 shows that the heat penetration rates for all of the runs were, in fact, similar and also not affected by process variables. It should be noted, however, that product temperature could be a variable as is indicated in run 5 (Table 1) or in a hypothetical case where a refrigerated product at, for example, 5°C was packed and canned. In this case, the initial temperature differential would be increased by more than a third.

While variations in T_{wb} did not have a profound effect on the rate of heat penetration into the cold spot, T_{wb} was still a most important parameter because the 35-min process did not start until T_{wb} = 100°C. The length of time required for T_{wb} to reach boiling must be related to the heating rate of the water in the canner. This heating rate would be affected by the heat input, the surface area and conductivity of the canner, heat losses, and of course, the mass of the water being heated. This latter parameter was the major source of the difference between the large canner and the small canner. Given the same heat input and losses, it took longer (25 min) to raise 18 liters of water from 97°C to 100°C than it did the lesser amount of water in the smaller canner. The worst case example (Table 1, run 11), reached T_{wb} = 100°C almost instantaneously with the result that the T_{cs} was only 24°C when the 35-min timed process started. The maximum T_{cs} in the saucepan reached

only 83°C and resulted in a process lethality of only 1 log with respect to *B. licheniformis* spores. In the case of the large canner (Table 1 run 2), the length of time required to reach T_{wb} of 100°C was so long that T_{cs} was 53°C at the start of the timed process, resulting in a maximum T_{cs} of 97°C and a calculated process lethality of 7.4 log reductions for the large canner.

The different lethalities obtained by different load sizes in a given canner could also be explained as an effect of m_{wb}. In this case, the volume lost by reducing the number of jars in the load was made up by an increased volume of water. This acted as a heat sink which decreased the amplitude of the T_{wb} drop when the jars were initially put in the canner. In addition, the mass of cold jars needed to affect the depression of T_{wb} was concurrently reduced. The net effect was that in a canner of a given size, when the number of jars was decreased, the water bath resumed boiling more rapidly and the lethality of the process decreased (Table 1, Fig. 3).

Collins et al. (1982) recently exploited a similar observation, but in a very different context with a very different result. They showed that reducing the amount of canner water used to process hot-pack tomato juice cut the come-up time and achieved energy savings without compromising the process lethality. Their approach was applicable for hot-packed juice because the energy supplied was needed only to maintain the temperature of the hot-packed product during the process. Heat penetration in a hot-packed, convection heated product is obviously much better than through a cold-packed, *conduction* heated menstruum. Both the high water level and low water level process used in that study maintained the cold spot temperature of 93°C for the entire 15-min process. This temperature was higher than the transient maximum temperatures achieved in any of the small canner and 66% of the large canner runs in this report.

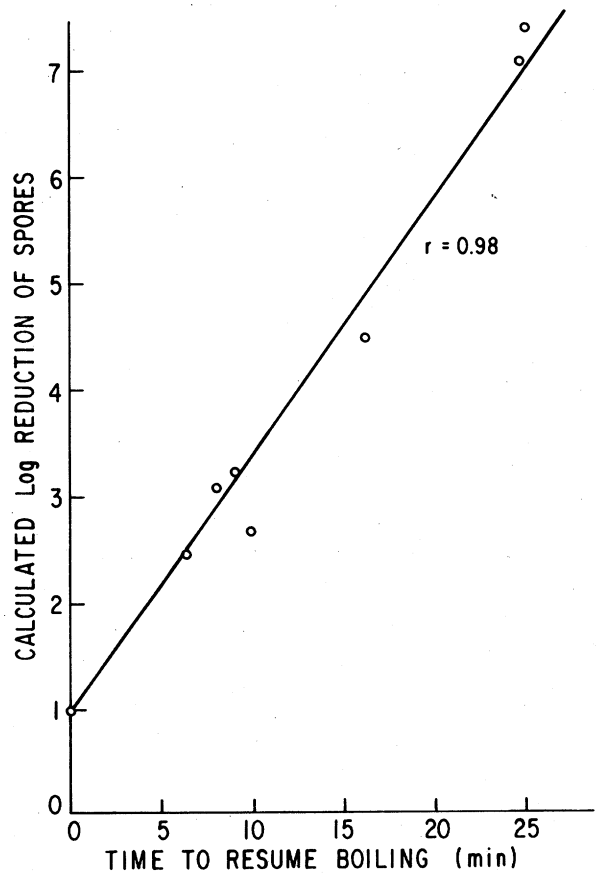

Fig. 3—Relationship between time required for water to resume boiling and the calculated total process lethality with respect to B. licheniformis spores.

Any factor which increased the time required for the water to resume boiling delayed the start of the timed process (Table 1). As a result, the timed process started with a higher initial T_{cs}, and a higher maximum T_{cs}, which added to the lethality contributed by the cool-down period, was achieved. In pressure canning, the cool-down period contributes between 18% and 50% of the total process lethality (Esselen and Tischer, 1945; Toepper et al., 1946). We have calculated that, for the raw pack processes in this study, the cool-down period contributes between 63% and 77% of the total process lethality. The contribution of the come-up period per se to the process lethality was negligible because temperatures below 60°C have negligible lethality to *B. licheniformis* spores. While runs with similar come-up times had similar process lethalities, uncontrollable variables such as heat input and ambient temperature could cause replicate runs of the same canner to have different come-up times and process lethalities. Regardless of which process variables were manipulated to alter the come-up times, the length of the come-up period was highly correlated (r = 0.98) with the resultant calculated process lethality (Fig. 3).

Thompson et al. (1979) have pointed out that errors in home canning can be the result of mistakes and equipment variation in the home or the use of incorrect measurements and faulty assumptions during the development of home canning recommendations. The data presented here demonstrate that the underlying assumption of the USDA raw-pack process, i.e., that the actual process time is the major determinant of process lethality, was faulty. We have shown that the process lethality was influenced by a multiplicity of factors. Because it would be difficult to control all of these parameters, the process must be considered inherently variable. Errors in the home would undoubtedly compound the problem.

The generation of process recommendations based on every canner, load size, and water level combination would be a cumbersome, confusing, and costly endeavor that would create chaos in the canning community. Simply adding time to the process would increase the lethality (Table 2) and reduce losses from spoilage, but would not solve the underlying problem of process variability. Better approaches might be to specify a minimum total jar residency period including the 35 min when the water is boiling, to better define the canning conditions under which the specified process will achieve the desired lethality, or to use hot-pack processes which better define the initial product temperature. Until the problems inherent to the raw-pack boiling water bath process can be resolved, the USDA has taken the position (personal communication, Milton Baldauf) that the raw-pack method should not be used to process tomatoes. The new recommendations are

—Continued on page 1597

Table 2—Comparison of variability in the lethality of 35-min and 45-min processes for raw-pack tomatoes

Processing conditions	Calculated lethality for *B. licheniformis* spores, number of log reductions	
	35-min process	45-min process
Large canner, 8 jars	4.5-7.4	5.1-9.9
Large canner, 4 jars	3.1	6.3
Small canner, 6 jars	2.7-3.2	5.6
Small canner, 3 jars	2.5	3.3

to use a hot-pack process of 35 min for pint jars and 45 min for quarts.

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